Kaibab Trail Suspension Bridge
Over Colorado River
Grand Canyon National Park
Coconino County
Arizona

HAER No. AZ-1

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3-GRACAN,
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PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

Historic American Engineering Record
National Park Service
Department of the Interior
Washington, D. C. 20240

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Kaibab Trail Suspension Bridge

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Location:	Over the Colorado River Grand Canyon National Park Coconino County, Arizona
Date of Construction:	1928; built to replace an earlier bridge built on the site in 1920
Engineers:	Designed by Ward P. Webber Built under the direction of John H. Lawrence
Owner:	National Park Service
Significance:	This is the site of the first bridge crossing of the Colorado River within the Grand Canyon National Park. It comprises an excellent example of an early 20th century suspension bridge designed for light traffic loads.
Written data prepared by:	Ward P. Webber and John H. Lawrence, 1929
Prepared for transmittal by:	Donald C. Jackson and Jean P. Yearby, 1984

REPORT ON DESIGN OF THE KAIBAB TRAIL BRIDGE

ACROSS COLORADO RIVER

IN GRAND CANYON NATIONAL PARK ARIZONA

By Ward P. Webber, Designing Engineer

(February, 1929)

In 1920 the National Park Service constructed a trail suspension bridge across the Colorado River at the foot of the "Bright Angel Trail" in Grand Canyon National Park. This structure attracted considerable attention at the time as it was the first bridge to be built within the confines of of the canyon and afforded the only safe means of crossing the river in a stretch of several hundred miles. The completion of this bridge made it possible to travel by saddle horse from the South Rim to the North Rim for the first time in the history of the park.

New Bridge Required.

As the park developed the number of visitors increased annually and better facilties for travel to the various point of interest became necessary. During 1920 and 1927 the National Park Service constructed one unit in the improved trail program, the Kaibab Trail, to provide a more direct route across the canyon. The site of the original river crossing was retained as it was admirably situated but the first bridge was too light and elastic to accomodate the increased traffic safely and a stronger and more rigid structure became necessary.

Controlling Factors in Design.

In selecting a new design one of the controlling factors was the high cost of transporting materials from the canyon rim down to the bottom. This distance is approximately four miles in an air line and drops 4750 feet in elevation. The distance by trail, which has many sharp turns and switchbacks, is seven and one half miles. Several methods were considered, among them being the construction of a cableway, but a careful study led to the selection of pack animals for transportation as being more satisfactory and economical.

This decision fixed the length and weight of individual rigid members which could be used economically in the new structure as it is difficult and expensive to transport by pack train pieces having a length over ten feet or weighing more than 200 pounds.

Fundamental Data.

Following are the main dimensions of the new suspension bridge as designed:

Bridge stiffening truss - length span	440 ft.
Cable span	500 "
Cable sag	55 "
Weight each cable	1.16 Tons
Weight entire structure	108.0 "
Depth of stiffening truss	8 ft.
Width of bridge, C to C of trusses	5 "
Panel length	9'-2 inches

Main Bridge Cables

Loading.

Stresses in the main cables were calculated for a live load of 100 lbs. and dead load of 280 lbs. per linear foot of bridge per cable. The live load was based upon an assumed continous line of loaded pack animals extending across the bridge and includes an allowance of 40% for impact.

The dead load was calculated from the preliminary design and agreed so closely with the final weight that no change was necessary.

Main Cable Section.

The combined loading amounting to 380 lbs. per linear foot of bridge per cable give a maxium tensile stress of 103.8 tons in each cable. The computation is as follows:

Horizontal component of stress = H = $\frac{w \times l_1 \times l_2}{8\ f}$

Where w = 380" = total load per ft.

l_1 = 500' = cable span

l_2 = 440' = length of load

f = 55' = cable sag

Substituting

$$H = \frac{380 \times 500 \times 440}{8 \times 55} = 190000 \text{ pounds}$$

Maximum Stress = H x sec. α = 190000 x 1.093 = 207670 lbs.

Where α = angle of inclination of cable at supports.

207670 pounds = 103.83 tons Max. stress.

With a factor of safety of three and one half this would require a cable approximately 3" in diameter. A cable of this size would be extremely stiff and its transportation down a narrow trail having many sharp bends and switchbacks would be nearly impossible with the added danger of having the galvanizing destroyed and the life of the cable impaired.

To minimize these difficulties, four 1-1/2" cables were adopted for each of the main bridge cables. Although these smaller cables were much more flexible and greatly reduced in weight, the cost of transporting them to the bridge site was nearly as much as their original cost at the factory.

Total Strength.

The combined strength of each group of four 1-1/2" cables is 360 tons which gives a factor of safety of 3.47. The total strength of both clusters composing the main bridge cables is 720 tons.

Anchorage.

The main cable anchorages were provided with adjusting bolts which permit each individual cable to be regulated to its proper length. A similar adjustment was provided at each wind cable anchorage.

Each end of the stiffening truss was anchored to the abutments with toggle anchors which permit free expansion and contraction of the truss while holding it rigidly to grade and preventing side displacement from wind pressure.

Cable support.

Owing to the character of the cliffs at each end of the bridge site, it was possible to eliminate cable towers by providing low concrete footings set into the solid rock for each of the main cable bearings.

Stiffening Truss

Bending Moments.

The entire weight of the bridge together with the live load is supported by the main cables and anchorages. They were proportioned accordingly to sustain these loads. The stiffening truss however has its own weight supported by the cable and is called upon only to resist deformation caused by an unbalanced live loading. The maximum stress from this condition arises when only one half of the truss is covered with the full load. This load gives a maximum positive bending moment of 358,518 foot pounds as follows:

$$\text{Max Bending Moment, } M = \frac{W' \, l^2}{54} = \frac{100 \times 440 \times 440}{54} = 358{,}518 \text{ ft. lbs.}$$

$$\frac{358518}{8} = 44814 \text{ lbs. stress in top and bottom chord.}$$

$$\frac{44814}{12000} = 3.73 \text{ '' net area steel required T. \& B. Chord.}$$

Two 4" x 4" x 3/8" angles were selected having a net area of 4.6." In this case web thickness requirements and commercial sizes available controlled the final choice of angle to be used.

Shear.

Maximum positive shear occurs at the center of the truss during critical loading and amounts to 5500 pounds.

Maximum negative shears occurs at the abutment adjacent to the unloaded portion of the truss during critical loading and includes temperature stress. This amounts to an uplift of 5963 pounds. The truss anchorage was designed for an uplift of 6000 pounds.

Type of Truss.

In selecting the type of truss to be adopted consideration was given to the difficulty and expense of finding the pieces required during erection. The "Warren" truss was selected as the primary members are few and can be interchanged between panels. This simplified the yarding of the steel at the job and reduced the cost of erection by preventing delays while hunting for a particular member. Space at the bridge site for yarding material was extremely limited on account of the steepness of the cliffs.

Width.

The width adopted for the bridge was 5'-0" c to c of trusses and was done to facilitate pack train travel. A narrower bridge would be liable to interfere with loaded animals and a wider one would give more opportunity for animals to turn around and cause confusion in the line.

Floor System.

The isolated location of the bridge makes it necessary to have as little maintenance on the structure as is possible. With this end in view the floor system was built of 1/4" flat steel plates riveted rigidly to the floor beams and girders.

A 2" layer of "Laykold" - asphaltic concrete was spread on the steel plates to provide a durable wearing surface and a more secure footing for saddle and pack animals.

Wind Stresses.

The Grand Canyon is subject to occasional high winds which sweep through the gorge with tremendous force. So great is the power of these storms that on several occasions the floor system of the old bridge was turned completely over and tossed about violently. This made any attempt at crossing during even moderate wind conditions hazadous and impossible during heavy wind periods.

To further guard against any similar action with the new bridge, special care was taken to provide adequate wind bracing. Although the stiffening truss is constructed as a continous structure rigidly riveted together, the narrow width in comparison to its length tends toward elasticity. The necessary lateral strength is provided by two wind cables, one on each side, which are connected to the truss by wind gays similar to the vertical hangers. As an added precaution against excessive uplift the wind cables are dropped at an angle of 26 degrees below the bridge grade.

Materials.

Standard galvanized bridge cables were purchased under contract from the Llewellyn Iron Works of Los Angeles. It was tested in the lahoratory of the Raymond G. Osborne Co., testing and inspection engineers at Los Angeles, California. The steel meets all requirements of the Federal Specifications Board, Specifications No. 351.

The Laykold for pavement was purchased from the Bitumuls Corporation of San Francisco.

Bridge paint was manufactured for the job on National Park Service specification, by the Yates-Hulett Paint Co., San Francisco. Tests were made by the U.S. Bureau of Standards and the first lot was rejected. The second lot came up to specifications and was accepted.

REPORT ON CONSTRUCTION OF THE KAIBAB TRAIL BRIDGE

ACROSS COLORADO RIVER

IN GRAND CANYON NATIONAL PARK ARIZONA

By John H. Lawrence, Construction Engineer

(February, 1929)

Upon completion and approval of the plans and specifications, bids were taken and contracts awarded for all necessary bridge materials. The Lewellyn Iron Works of Los Angeles were awarded the contract for structural steel and the Hazzard Wire Rope Company of Pennsylvania, the contract for cables, cable clamps, sockets and anchorage steel.

Upon fabrication, all material was shipped by railroad to Grand Canyon and then trucked from there to the head of the Kaibab trail at Yaki Point, a distance of approximately 3-1/2 miles, by Grand Canyon National Park men and equipment.

Packing

With the exception of 26 tons of the structural steel, which was transported by the Fred Harvey Pack Train, all equipment, materials and supplies were transported from the head of the trail at Yaki Point to the bridge site on the floor of the canyon by the Grand Canyon Park Service pack train. The trail distance is approximately 7 miles and the vertical drop, over 5000 feet. The pack outfit consisted of three packers and 21 pack animals under the direct supervision of Mr. "Jack" Way, chief packer and under the general supervision of local Park Service officials. In this connection, it might be well to state that it was due to a very great extent, to Mr. Way's ability, energy and devotion to the work, that no interruptions occurred in delivery of needed material and supplies at the bridge. The excellence of his work is further attested by the fact that not one of the animals was injured or laid up from injuries during the entire period of packing.

The main cables which were each approximately 550 feet long and weighed over a ton, were each carried down on the shoulders of 42 men - mostly local Indians. Each man's share of the load was approximately 50 pounds. The round trip was made in two days.

The wind cable came in one piece about 900 feet long. It was cut to length at Yaki Point and sledded to the bridge site on a "go-devil" designed by the writer. This method showed considerable saving in cost over the method used in transporting the main cables, but could not be used for transporting the latter because of lack of time, as it required about two and one half times as long to transport by the sled system.

CONSTRUCTION

General

Camp was established at the junction of Bright Angel Creek and the Colorado River. The original construction force consisted of a bridge foreman, nine skilled lahorers and a cook. This force was later increased to 20 men practically all of whom were specialized laborers. Active construction began March 9, 1928 and the bridge and approaches were complete August 3, 1928. The new bridge was constructed at the site of the old bridge and approximately 16 feet above the new bridge which was used uninterruptedly by the public until the new bridge was opened to traffic.

Equipment

Construction equipment consisted to a great extent of air tools, wrenches, blocks and micellaneous small tools which were brought to the job from the Forest Service warehouse at San Francisco. Two old Ingersoll-Rand 80 cu. ft. air compressors furnished power for jack-hammers, rivet hammer and air hoist. The compressors were so ineffective that it was found necessary while drilling in the tunnel approach to hook both compressors on to one small jackhammer. This slowed up the work considerably, there being at times hardly enough air to run even the one drill.

Anchorages - North End

The north main cable anchorage was the first item of construction. The upstream pit for the cable anchorage was sunk about 14 ft. and the downstream pit four feet, into a rock formation locally called rose granite. In making this excavation, it was necessary to use very light blasts due to the danger of disturbing the anchorage of the old bridge. Forms for the concrete support for the anchorages were placed and concrete poured. After the concrete had set sufficiently the anchorage sttel was put in place and concrete placed to proper elevation. The rock which had been excavated from the anchorage pits was used as additional fill over the concrete, to a depth of approximately 4 feet. It is estimated by the writer that the north cable anchorage is good for a resistance to horizontal tension of over four hundred tons, and a vertical uplift one hundred and fifty tons.

Cable Supports - North Tower

After completion of the north anchorage a form was built around the old north cable support, extending the length two and one half feet upstream and downstream. This was to provide for the new cable supports, the saddles of which were hung in proper position inside the forms and concrete placed in the form up to the bottom of the saddles. Exact elevation of the saddles was determined and the saddles were grouted in place using a cement and sand morter.

Trail - North Approach

While the above work was in progress, excavation of the north approach trail was started. It had been decided by the writer after careful study of this approach, that the most feasible approach to construct would be by means of a spiral beginning at the grade of the old north abutment and spirally upstream and to the east, and then swinging south to the north abutment. This proved to be fairly easy construction and permitted using the old trail up to the north end of the old bridge, and upon completion, it gave an easy and pleasing approach to the north end of the new bridge.

North Abutment

The form for the north abutment was then erected, concrete placed and expansion connection and stiffening truss "wind bumpers" secured in position.

Anchorage - South End

Work had also been progressing on excavation of the south approach trail, the south anchorage pits and the south cable supports. Due to the fact that the south cable supports on the old bridge were approximately seven and one half feet above the north cable supports, it was impossible to make open cuts for passage of the cables. For this reason a tunnel was cut through the rocks for each up and down stream cable group. These tunnels were of necessity very small, as the rock was very blocky being of a mica schist formation, which together with the fact that the concrete dead man for the old south cable anchorage was directly over each new cable tunnel, rendered very hazardous any sizable excavation. These tunnels were about two feet by two feet six inches in cross section, the upstream one being seventeen feet in length and the downstream one eleven feet. All excavation in these tunnels was by hand, four pound hammers and gads being used to quarry out the rock.

Because of the fact that the old south downstream cable support was on very blocky and seamy rock, a temporary support was erected to insure safety of the existing bridge for use by tourists during erection of the new structure. This consisted of a frame of two eight inch by eight inch timbers about nine feet high which were supported on a temporary concrete pedestal and tied to the rock at right angles to the cable by means of one of the center steel stringers for the new bridge. This stringer which was an eight inch I-beam, also supported the cable, which was hung from it by two stirrups around the old cable support and the I-beam.

The south cable ancborage pits were next excavated and anchorage steel placed and concrete poured as described for the north anchorage. All steel and concrete for this anchorage was hoisted by means of the Sullivan air hoist, the hoist line being passed through a snatch block secured to the top a steel A frame on top of the old south anchorage, back down to a snatch block carrying a concrete skip on a high line running from the top of the A frame to an anchor in a large boulder near the concrete mixing box.

Cable Support - South Tower

The new south cable support positions were then determined and concrete pedestals placed to support the cable saddles. The upstream support was very difficult to place being inside of the low tunnel and at nearly as high an elevation as the tunnel ceiling. The cable saddles were then placed and grouted for accurate elevation with cement mortar.

Trail - South Approach Tunnel

Work was also progressing on the excavation of the south approach tunnel, excavation being carried on simultaneously from both the north and south portals. This tunnel is 105'0" long, with a cross section 10 feet high and 6 feet wide. The roof of the tunnel was arched as much as the blocky rock would permit. The bottom of the tunnel is a trench three feet wide for one and one half feet high, widening to six feet at this height. This permits of a tourist readily dismounting from his animal without danger of being trod upon by the animal and also prevents the animal from rubbing the tourist's legs against the walls. Rapid progress of this work was hindered by lack of sufficient compressed air for drilling. For this reason a night shift was employed to work from 6 p.m. until 2 a.m. They drilled and blasted in the north end of the tunnel and all excavated material was removed by the day shift muckers in wheelbarrows, to a chute at the north portal, thence into the river. The day shift worked in the south end of the tunnel drilling and blasting, and the excavated material was removed by the night shift. It took an average of seven hours to drill a round of seven holes, the other hour was required for loading and blasting. One round would "pull" from two to four feet depending on material encountered. All tunnel workers were required to wear respirators and goggles, as a protection against the fine rock dust.

During construction of the north portal it was necessary to resort to timbering due to the extreme danger of the possibility of some of the rock over the portal caving in. When the tunnel was completed, the portal was concreted to provide a permanent support for this rock.

Suspension Cables

The main cables were hoisted into position and attached to the anchorages. At the north end the air hoist was used to provide power for bringing the cables to the anchorage and after the ends were attached, the cables were hoisted into place on the support by means of a triple block. At the south end the cables were elevated into final position by means of a thirty ton hand operated stump puller then attached to the anchorages.

Hanger Cables

After all the cables were up, they were adjusted to predetermined proper postion. A rigger and the writer then went out on the cables in "bos'nz" chairs and measured and marked the cables for the hanger cable positions.

Attachment of the hanger cables to the main cables and assembly of transoms was started from the south end of the bridge, and accomplished in the following manner: The transom, consisting of a floorbeam and two verticals, was brought out on the old bridge by six men, and placed directly under tis corresponding position in the new structure. The hanger cables were then attached to the floor-beam and the entire assembly hoisted by means of a set of tackle hanging from each cable group, at the point of the panel being raised. A rigger sitting in a "bos'nz" chair suspended from each cable group then attached the hanger cable to the cable group.

Steel Erection

Meanwhile considerable progress had been made by the structural workers in assembling and riveting the steel floor beam and stringer sections and the steel floor plates.

Previous to completion of hanging the transoms, the tunnel was "holed through" and enlarged sufficiently to permit transporting materials directly on to the bridge. A seven-eighths inch diameter cable for use as a high line was stretched across over the center-line of the bridge and secured to the cable anchorages. A large snatch block, from which was suspended a set of triple block tackle, was placed on the cable and regulated by means of two haul-back lines. The sections consisting of an intermediate floorbeam to which had been riveted the three stringers on each side of it and also the bottom laterals, were then brought out one at a time through the tunnel on a hand cart, raised to within a few feet of high line by means of the triple tackle, let out on the high line to a position over their final location, then lowered and secured to the adjoining floorbeams by erection bolts. These were the most difficult members of the entire structure to place, because of their length and weight. It was also one of the most hazardous phases of the construction as the riggers had to ride the steel to make the flying connection to the swinging floorbeams. As fast as these sections were brought out and placed the floor plates and guard angles were bolted in place. This method of construction was followed until completion of assembly of the floor system. The stiffening truss was then erected in the following order; bottom chords, intermediate verticals, diagonals and finally the top chords.

Wind or Side Sway Cables

Upon completion of the erection of the steel, the wind cables were cut and socketed and secured to their respective anchorages which had been prepared during erection of the stiffening truss. The south upstream wind cable anchorage was quite difficult to place. It was necessary for the jack hammer operator to hang in a sling from two ropes one hundred and twenty five feet below where the rope was secured and with a seventy foot sheer wall to the river below him.

Adjust Main Cables - Suspension

The main cables were then adjusted for final position and covers placed on the saddles.

Adjustment Wind Cables

The wind cable guys were then attached to the wind cables and adjusted to proper length.

Riveting of Structure

The next work was completion of the field riveting of the truss, to replace the temporary erection bolts, after which the wire fence and the three guard rails were bolted in place.

Bridge Floor Pavement

A two inch surfacing was then applied to the floor. This surfacing was prepared by mixing a screened gravel and sand aggregate with a preparation of cold asphalt emulsion, the trade name of which, is "Lay Kold." The proportion used was one part "Lay Kold" to four parts of aggregrate. The "Lay Kold" asphalt emulsion was shipped from the plant in Oakland, California to the job in five gallon tins. These small containers were necessary to facilitate transportion by pack animals. The aggregate was obtained from a pit near the bridge site.

The materials in the proper proportion and water were introduced into a small concrete mixer and mixed, then placed in the same manner as concrete. After hardening, this produced a durable and waterproof pavement without the use of heating equipment which effected a decided saving in time and freighting costs.

After placing the bridge floor the stiffening truss was connected to the abutments through the expansion joints and painted, after which the structure was ready for traffic.

Removal of Old Bridge

The old bridge was then removed piece by piece, working both ways from the center. All material was carried ashore and stored in a pile for use on various other bridge projects.

Acknowledgements

The writer wished to express his appreciation of the hearty cooperation extended him by Mr. M.R. Tillotson, Superintendent, Mr. Clark M. Carrel, Park Engineer, and other members of the U.S. National Park Service while at Grand Canyon on this work.

Considerable credit should also be given to Mr. W. G. Mitchell, my bridge foreman, who rendered very excellent assistance in construction of the project.

Items of Interest

There are 67 tons of structural steel in the bridge.

There are 11,000 field rivets in the bridge.

The cost of packing the main cables down to the bridge site was more than the fabricated cost of the cables.

There were no serious injuries on this construction job, the most serious being a broken bone in a rigger's foot.

There was no piece of steel or other material dropped into the river.

There were approximately 122 tons of material and supplies packed to the bridge.

The new bridge will support all the live load that can be placed on it.

The high line used on the bridge was the cable that formerly carried traffic across the river and upon which Theodore Roosevelt crossed.

Not a pack animal was laid up from injuries received from packing the material.

The approximate breaking strength of each cable group is 360 tons.

For two full weeks there were seven packers, 42 pack animals and seven saddle animals packing to the bridge every day.

It required three months to pack the main part of the bridge material and supplies and equipment to the bridge.